IDENTIFICATION OF WINTER WEATHER TYPES OF THE EASTERN NORTH PACIFIC BY MEANS OF A PARTIAL ZONAL INDEX

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PART I

Introduction

In case of war, the weather information available to the U.S. Naval Service in the Pacific would probably be reduced to observations from continental North America and from a few island possessions. It is the purpose of this study to contribute to the problem of forecasting for this area under such conditions.

In 1940, Dorsett and Kosco initiated a new research on this subject entitled "Winter Weather Types of the Eastern North Pacific and Adjacent Coastal and Island Areas"; copies of this paper have been furnished to Navy Aerological offices. It contains a classification of seven winter weather types, a statistical analysis of the distribution of weather for each type and a detailed description of the indications and trends for these types.

The indications given by Dorsett and Kosco for identifying the existing types were observations of clouds, precipitation, pressure,

PART I

Introduction

In view of very low-weather [illegible] activity by the U.S. Naval service in the Pacific areas [illegible] in [illegible] from continental North America and from a few island [illegible]. It is the purpose of this study to contribute to the problem of forecasting [illegible] under such conditions.

In 1942, [illegible] and [illegible] initiated a new approach to this subject studying weather types of the eastern North Pacific and adjacent coastal and inland [illegible] of west coast have been re- lated to [illegible] criteria. It contains a classification of seven winter weather types, a statistical analysis of the [illegible] of weather for each type and a detailed explanation of the [illegible] and trends for these types.

The indications given by [illegible], [illegible] the [illegible] the existing types [illegible] of [illegible], precipitation, [illegible]

pressure tendency, and winds from the coastal and island stations. The present authors observed that the available information from continental North America furnishes means for the accurate determination of a partial zonal index covering sixty degrees of longitude and that the index can be extended by means of the island observations to cover one hundred and twenty degrees of longitude with reasonable accuracy. This furnishes a potential means of identifying weather types and predicting trends. C. G. Rossby and collaborators have established a close connection between certain weather types and the total zonal index in the development of the five-day forecasting project at M.I.T. It was decided to investigate the practicability of identifying and forecasting the weather types evolved by Dorsett and Kosco by means of the available partial indices.

This necessarily involves a statistical approach and the authors entered upon it with some reluctance, fully realizing the limitations of numerical correlations and the pitfalls of wishful interpretation of statistics, particularly when applied to relatively small

samples. The field is quite attractive, however, especially in considering the usefulness of the zonal index as it has been employed by the long range forecasters at M.I.T.

The material employed in this investigation includes:

(1) Deutsche Seewarte Northern Hemisphere Synoptic Maps for December, January, February of the Polar Year 1932-1933.

(2) M.I.T. Official Northern Hemisphere surface maps from 1 January 1939 to 12 March 1939 and from 20 November 1940 to 25 February 1941.

In choosing this material, care was taken to span a long enough period to include possible long period variation in weather trends and to use the most reliable and accurate analyses available. The material includes two hundred and forty nine carefully analyzed Northern Hemisphere maps. The winter periods investigated were extended into the fall and spring in order to test the applicability of the weather types to the changing seasons.

PART II

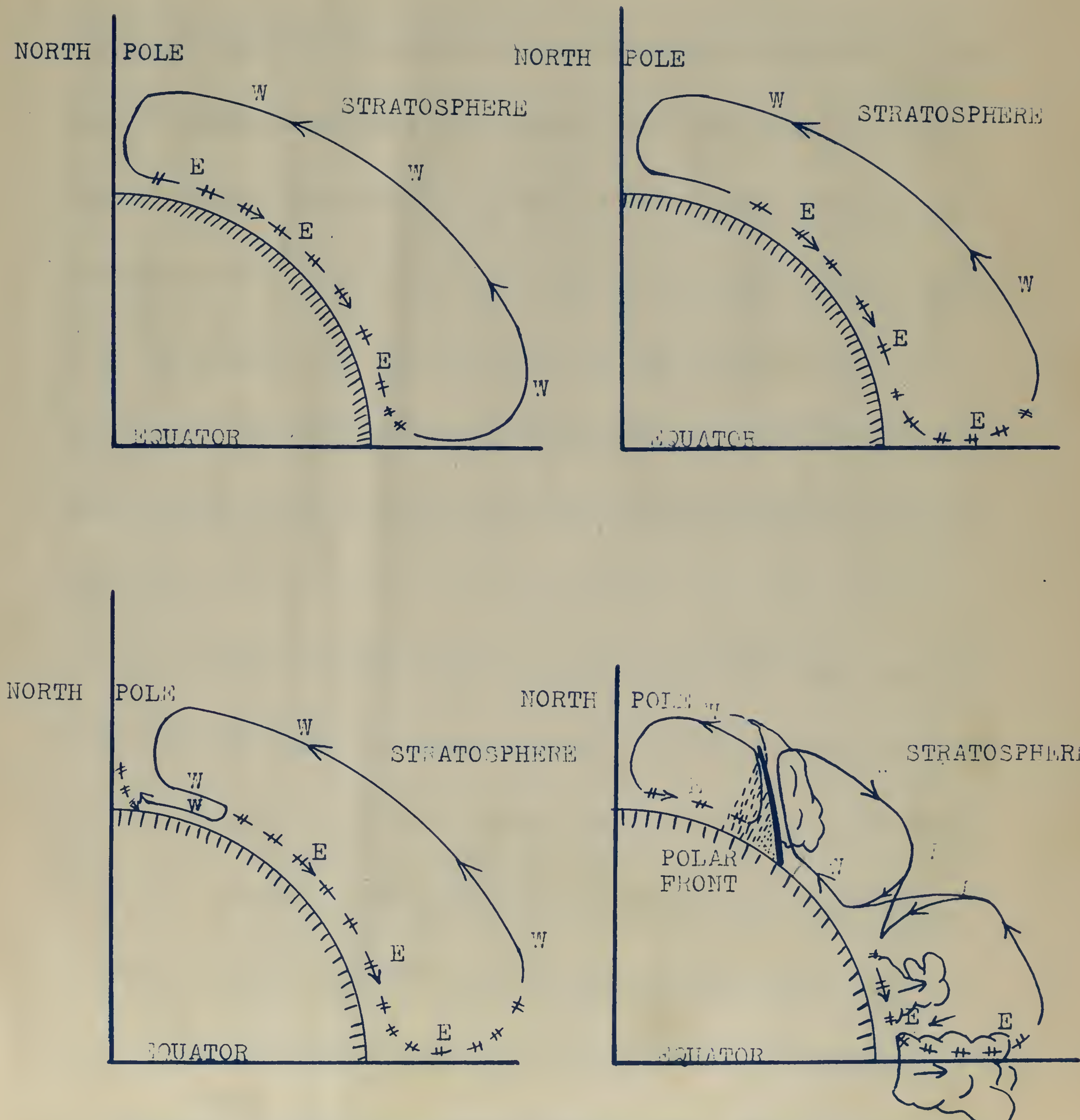
<u>The General Circulation of the Atmosphere</u>

Upon the understanding of the dynamic and thermodynamic processes involved in setting up and maintaining the movements of the atmosphere, depends the ability to understand and to predict the weather processes. The importance of this basic understanding increases as the attempt to forecast is extended either into space or time. Only as more is learned of the causes of the circulation of the earth's atmosphere can improvement be made in forecasting for longer periods of time or in extending forecasts into regions of no reports.

In developing the five-day forecasting project at M.I.T., Rossby and his collaborators have made marked progress of late years in the direction of synthesizing by theory the general circulation of the atmosphere as it is known to exist. Since it is essential to an understanding of the significance of the zonal index, the theory will be briefly summarized here.

If the earth were perfectly smooth, homogeneous, did not rotate, and the heat received from the sun were uniformly distributed in a band about the equator, a simple meridional circulation would result. In this circulation, the heated equatorial air would rise and the cooled polar air would sink, resulting in a pressure gradient toward the pole at high levels and toward the equator at the surface. As a result, the path of air particles would be: rising at the equator, northward aloft, sinking at the pole and southward along the surface to the equator.

If, now, the earth were set in rotational motion about the polar axis and surface friction brought into play, the above described circulation would break down as shown in Plate I (page 6). First, the deflecting force due to earth's rotation would cause the horizontal velocities to turn toward the right (in northern hemisphere) resulting in a component of westerly winds aloft and easterly winds at the surface (Figure A). Inertia would result in bringing down of westerly winds at



Dynamics of the Breakdown of Meridional Circulation under the Influence of the Earth's Rotation and of Surface Friction.

(From Notes on the General Circulation of the Atmosphere by C.G. ROSSBY.)

As these motions are established, the pressure distribution must continually adapt itself to the motion. This gives rise to a sea level pressure maximum between the easterly and westerly surface components in Figure B. The surface winds near the pole must be subjected to frictional retardation which will result in the turning of the stream northward again, under the influence of the pressure built up to the south (Figure C). Since the air continues to cool and sink at the pole, this returning air must be forced aloft, so establishing the cellular circulation shown in Figure D.

It is desirable, now, to consider the energy which maintains each cell. The equatorial and polar cells may be called direct cells in the sense that they carry heat from heat source to cold source, so transforming the potential energy of heat difference into kinetic energy of the air particles. The central cell, however, has the reverse circulation, and it remains to account for its energy source. This is furnished in the form of viscous drag by the two direct cells. In other words, the

strong westerly winds of the adjacent cells to the North and South create eddies with approximately vertical axes. Through the action of these eddies the momentum of the Westerlies is scattered throughout the central cell. The excess of centrifugal force possessed by the west winds of middle latitudes forces them southward, but equilibrium is never reached because the air particles still farther south lose heat by radiation, sink, and acquire a northward, pressure driven movement.

The velocity of these frictionally driven Westerlies is necessarily reflected in the pressure differences observed at the surface, as, indeed, are all of the above described atmospheric motions. Consequently, the pressure difference between the limits of the Westerlies must then give a good indication of the relative strength of the Westerlies.

By summing the pressure values around each latitude circle in the Northern Hemisphere sea level pressure maps, a profile of the mean meridional pressure distribution can be drawn. This was done for daily, monthly, and annual pressure means and it was determined that

the minimum and the maximum in the mean profile lay at nearly 55° North and 35° North respectively. The difference between the means of the pressures about the 55° North latitude circle and about the 35° North latitude circle was consequently taken as an indication of the strength of the Westerlies and was called the <u>zonal index</u>.

By considerations involving the conservation of absolute vorticity, Rossby has shown that the westerly winds are stable in character, that is, if they are disturbed, as by frictional and thermal changes across continental coasts, they adopt sinusoidal paths but maintain their essentially eastward flow. Such sinusoidal patterns may be seen on any high level pressure chart. Moreover, it was shown that the following relation holds:

$$c = U\left(1 - \frac{L^2}{L_s^2}\right)$$

where c = eastward speed of the sinusoidal perturbation (trough or wedge)
U = velocity of the zonal westerly wind
L = wave length of the perturbation
L_s = wave length of the perturbation for which c is zero ("standing wave length")*

* Note: $L_s = 2\pi\sqrt{\frac{UR}{2\Omega\cos\phi}}$ where R = radius of the earth, Ω = angular velocity of the earth and ϕ = the latitude.

It is further shown that the number (n) of such perturbations is given by $n = \sqrt{\dfrac{2\Omega R\cos^3\phi}{U-c}}$

Since these theoretical considerations establish that the number of troughs and wedges in middle latitudes and the rate of their movement are functions of the intensity of the Westerlies, it is seen that there must be a close relationship between weather patterns and their changes at the surface (pressure distribution) and the zonal index (which is a measure of the intensity of the Westerlies).

PART III

The Zonal Index

As described above, the zonal index is the average pressure about the 55° North latitude circle subtracted from the average pressure about the 35° North latitude circle. It is an indication of the average intensity of the zonal circulation between those latitudes. Positive values of the zonal index indicate average eastward flow and negative values indicate average westward flow. The zonal index may be subdivided into partial indices which show the difference between the average pressures along the same latitude circles but between certain longitude limits.

In this paper, two partial indices are used. One, between 60° West and 120° West longitude is called the "Continental Index"; the other, between 60° West and 160° West, is called the "Continental-Pacific Index".

To compute the zonal index or a partial index, the isobars must first be drawn from the available observations. Then the pressure

value for each two degrees of longitude is tabulated and summed for the 35° North latitude circle; the corresponding sum is obtained along the 55° North latitude circle. The 55° latitude sum is subtracted from the 35° latitude sum and the difference divided by the number of pressure readings used along each latitude.

It is to be observed that the land reports from the United States and Canada establish an accurate "Continental Index", but that the accuracy of the "Continental-Pacific Index" must depend upon the available reports from the Pacific. It has been found that a satisfactorily accurate "Continental-Pacific Index" can be computed by means of observations from Pearl Harbor, Midway, Dutch Harbor, Kanaga, and Sitka in addition to the usual United States and Canadian reports.

It has been assumed in this study that the "Continental-Pacific Index", since it is more comprehensive, is the better index to indicate weather types. The high correlation factor found, however, between it and the "Continental Index" ($r = .820$) shows that either might be used with substantially equivalent result.

When the daily values of the two indices had been computed, it was observed that the trend of the values was quite regular but that the variation in day to day values was quite marked, giving a more or less saw-toothed curve. It was decided, therefore, to follow the practice of the long-range forecasting group and use five-day mean values. All index values shown in this paper are of five-day running means, that is, the average of the values for the named date and of the four preceding days. The effect of this practice is to minimize the influence on the index of individual migrating centers and to give more weight to the intensity, position, and changes of the quasi-permanent centers. This is more significant of the large-scale weather type classification treated here.

It should be mentioned that the zonal index may not be the best available measure of the intensity of the middle latitude circulation, and in some cases may be actually misleading. The proposal has been made that the mean pressure profiles between the longitude limits

be drawn from the available readings, and the slope of the profile, or the maximum pressure difference along the profile, be used in its stead. This represents a longer computation in each case, but its greater representativeness is beyond doubt. The use of such profiles is a possible refinement on the present work and is suggested for future study.

PART IV

The Weather Types

No classification of weather situations into types will provide a wholly satisfactory description of any one synoptic situation. These types have not been evolved with the idea that their application will furnish an accurate forecast of the weather at a given point. They do, however, serve to show a general distribution of winds and weather and to point out the most likely regions of favorable and unfavorable conditions.

The types used here are those evolved by Dorsett and Kosco in 1940. They were developed after a careful study of the winter maps prepared for the Polar Year 1932-1933 by the Deutsche Seewarte. All maps during the period were placed within one or another of the seven types, which had for their basic criterion, the orientation and extent of the Pacific subtropical high pressure area.

The present authors set about to test the rigidity of the classification and to determine how well the types could be applied to

other winter periods. In classifying the maps for 1932-1933 independently, the original classification was found to be substantially indisputable in 80 per cent of the cases. Considering that there must unquestionably be periods of transition from one type to the next, during which the type may be quite indistinct, and that in at least some cases this transition must require more than the twenty-four hours elapsed between each map, it was concluded that for that winter, at least, the type classification was excellent. Classification was extended to the winter months of 1939 and of 1940-1941 and the maps found to be satisfactorily assignable to the types already established.

Attempt was made to extend the classification into the spring of 1939 and into the fall of 1940. It was found that the types became more and more indistinct and there were periods of days when the maps could not be grouped into the types as defined. This would indicate that the classification is indeed applicable only to the winter seasons.

In testing the original Polar Year classification, careful consideration of the eighteen maps not clearly falling within the types

as originally described, led to the addition of several new criteria to the original type descriptions. This furnished sufficient ground, in the opinion of the authors, to reclassify these maps more rigidly.

The detailed type descriptions used here are set forth on Plates II to VIII inclusive (pages 28-34). A careful application of the complete detailed description is necessary in making classifications. A brief summary of each type is contained in the following table:

Type	Orientation of Axis of Pacific High
A	East - west
B	Northeast - southwest
C	North - south in eastern part of area
D_1	Northwest - southeast with deepening low in northern part of area and reinforcement of Pacific High from the north or northwest
D_2	Northwest - southeast
E	North - south in western part of area
F	Practically no high, or high displaced far southward resulting in domination of whole area by cyclonic circulation

In the development of the five-day forecasting project at M.I.T., certain general conclusions have been drawn with regard to the connection between the intensity of the Westerlies and the middle latitude weather patterns. These conclusions concern, chiefly, the intensity

and location of the subpermanent centers, such as the Aleutian and Icelandic Lows, the Pacific and Bermuda Highs, etc. From these conclusions, it is seen that types A and B are typical of high zonal index and that the remaining types are typical of more or less low index. It is interesting to observe that the following statistical study confirms these conclusions.

PART V

Analysis of the Statistical Investigation

From an examination of the three winter curves of the Continental and Continental Pacific Indices (Plates II, X and XI, pages 35, 36 and 37), the high correlation is at once apparent. As the former comprises seven-thirteenths of the latter, a certain correlation is to be expected. This expected correlation (r_n) was computed from the formula $r_n = \frac{\sqrt{\Sigma C^2}}{\sqrt{\Sigma T^2}}$ where Σ indicates summation, C, the values of the Continental Index, and T, the values of the Continental Pacific Index. It was found to be .685 for the total period investigated. The actual correlation was computed from the usual formula for the correlation factor:

$$r = \frac{\Sigma(TC) - \frac{(\Sigma T)(\Sigma C)}{N}}{\sqrt{\left[\Sigma T^2 - \frac{(\Sigma T)^2}{N}\right]\left[\Sigma C^2 - \frac{(\Sigma C)^2}{N}\right]}}$$

where N indicates the total number of values used and other symbols same as above. This was found to be .820. The difference between these factors, .135, indicates the independent correlation between the two curves due to an innate cause and effect relationship quite apart from that due to their mutual composition. This is a relatively high factor in statistical experience.

For the purpose of determining the value of the Continental-Pacific Index from the Continental Index, or of using one index in place of the other for correlation with weather types, the significant factor is .880. This factor may be said to mean that the variation in one index accounts for 88 per cent of the variation in the other.

Another feature of the curves that seems significant is the difference in the periodicity from winter to winter. During the winter of 1932-1933, the periods were all fairly long and the amplitudes quite large, resulting in three general maxima for the season. During the winter of 1938-1939, the periods were all short (with one moderate exception) and the amplitude small. During the winter of 1940-1941, the periods were all moderate and the amplitudes moderate. This continuity of period and amplitude for each season is well marked for these data and may warrant further investigation for its application to forecasting the zonal index for long periods ahead. This might furnish good basis for long range forecasting.

Although the weather types under investigation were not set up with an idea of any relation to the zonal index, it is obvious upon a study of the types, that each represents a fundamentally different general circulation rather than just different pressure patterns. Considering the middle latitudes, Type A represents a general east - west flow, B a southwest - northeast flow, C a south - north flow, D_1 a transition stage becoming D_2 and a northwest - southeast flow, E a north - south flow, and F a more or less indeterminate flow depending upon the number and location of the cyclonic systems. If, then, the types represent different general flow patterns, they should bear some sort of relation to the zonal index which is itself a measure of the intensity of the middle latitude flow.

Plates XII, XIII and XIV (pages 38, 39 and 40) represent graphically an attempt to find the form of this relationship. Plate XII (page 38) represents the distribution of the frequency of each type about the zero Continental-Pacific Index. (For example, Type A occurred five times with an index of plus 6, five times with an index of plus 12, etc.)

From this distribution, it may be seen that Types A and B are high index types, Type C is a low index type, and the others are moderate index types.

Plate XIII (page 39) gives the distribution of the frequency of each type about the mean Continental-Pacific Index for its own winter. (For example, Type A occurred five times when the index was at the mean value for that winter, four times when the index was one millibar above the mean value for that winter, etc.) This distribution brings out clearly that A and B are considerably higher than average index types and C is definitely lower than average. Types D_1 and D_2 also show a definite grouping below the average index, but still higher than C.

Plate XIV (page 40) represents the distribution of the frequency of each type about the mean zonal index for the entire period investigated. This distribution shows nothing new but is included to complete the statistical analysis.

Another potential indication of types, or type changes, is the sign of the change in the zonal index. A thorough search was made in an attempt to establish any relationships between the rises and falls

of the index with any types or shift in types. The results of the investigation of 1932-1933 showed fair promise. Type C was definitely falling index type. Type F was in all cases associated with a rising index. Type D_1 was largely a falling index type. These conclusions were substantiated by the 1939 analysis except for D_1, which was replaced by D_2 as a better than two to one falling index type, and for F which, though rare, showed <u>no</u> rising indices. The analysis of 1940-1941 spoiled nearly all hope of drawing any conclusion from this source, as none of the previous indications held. It is only fair to state, however, that few of the types during 1940-1941 were as clear-cut as in previous years. This seemed to be due to the fact that 1940-1941 was a low index season throughout, and consequently, in agreement with Rossby's theoretical conclusion, no well-defined systems should be found.

The following table shows the distribution of tendencies of the index for the period immediately preceding each type occurrence, and the average values of the Continental-Pacific Index. In determining the sign of the tendency, any change of less than .5 millibars was

considered insignificant unless preceded by a general well marked tendency in the same direction. Such small change is recorded as a "no change" (NC) tendency.

Types	A			B			C			D_1			D_2			E			F			
Tendencies	+	-	NC	+	-	NC	+	-	NC	+	-	NC	+	-	NC	+	-	NC	+	-	NC	Mean Index
1932-1933	13	9	1	10	9	3	4	12	2	2	6	2	2	2	3	2	2	0	5	0	0	12.8
1939	8	4	3	6	6	4	0	4	2	4	5	2	3	7	2	1	3	0	0	2	1	10.0
1940-1941	6	0	0	6	2	5	8	5	0	0	1	0	0	1	0	3	6	2	12	17	10	5.7
Totals	27	13	4	22	17	12	12	21	4	6	12	4	5	10	5	6	11	2	17	19	11	8.8
Average Continental-Pacific Index	14.0			13.4			5.6			8.7			8.4			6.0			6.5			

PART VI

Summary and Conclusions

The ideal result of this investigation would be such that it would be possible to compute the partial zonal index daily, plot its value or the value of its running mean, and then determine, from its magnitude, the existing weather type; also, from its trend, to forecast the next succeeding type and when it would prevail. This would be a strong tool in the hand of the forecaster who is denied synoptic ocean reports and would enable him to determine favorable and unfavorable areas for sea and air operations well in advance.

The investigation has led to no such ideal result. It has, however, led to certain conclusions which are tabulated below:

(1) The weather types as evolved by Dorsett and Kosco for the Polar Winter 1932-1933, and as here described, are sufficiently distinct and exemplary for classifying other winters.

(2) The types are applicable only to winter seasons.

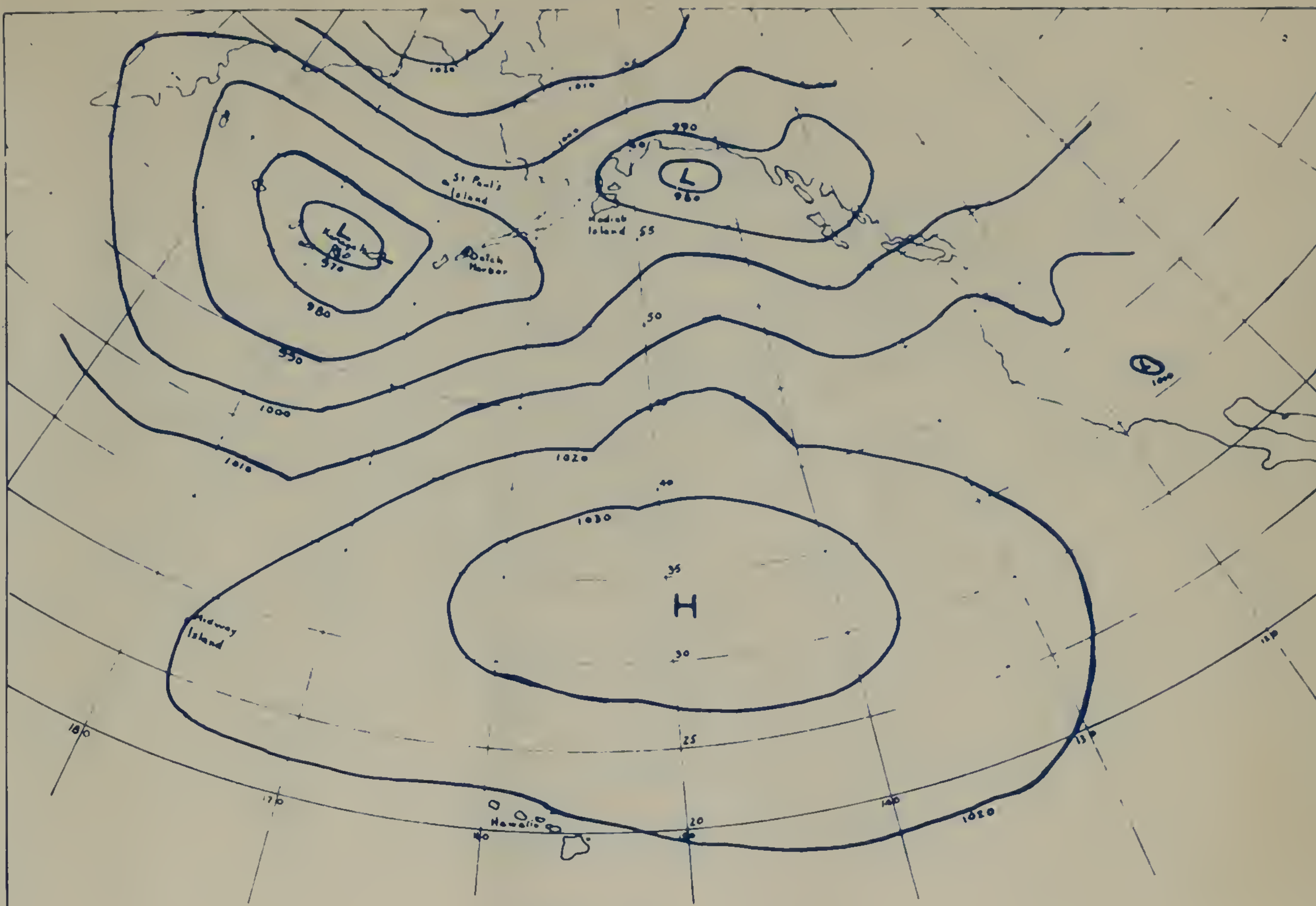
(3) Types A and B are characteristic of a high partial zonal index, Type C, of a low index, and Types D_1, D_2, E, and F, of a moderate index.

(4) The partial zonal index from 60° West to 120° West and that from 60° West to 180° West have a correlation factor of .820, and an independent correlation of .155. It is possible to estimate one index from the other with commensurate accuracy.

(5) The weather types are less well defined in winters of relatively low average partial zonal index.

(6) Individual winters show marked characteristics of period and amplitude in the partial zonal index curves, and these characteristics tend to persist unchanged throughout the season. Small amplitude is associated with short period, moderate amplitude with moderate period, and large amplitude with long period.

PLATE NO. II



TYPE A

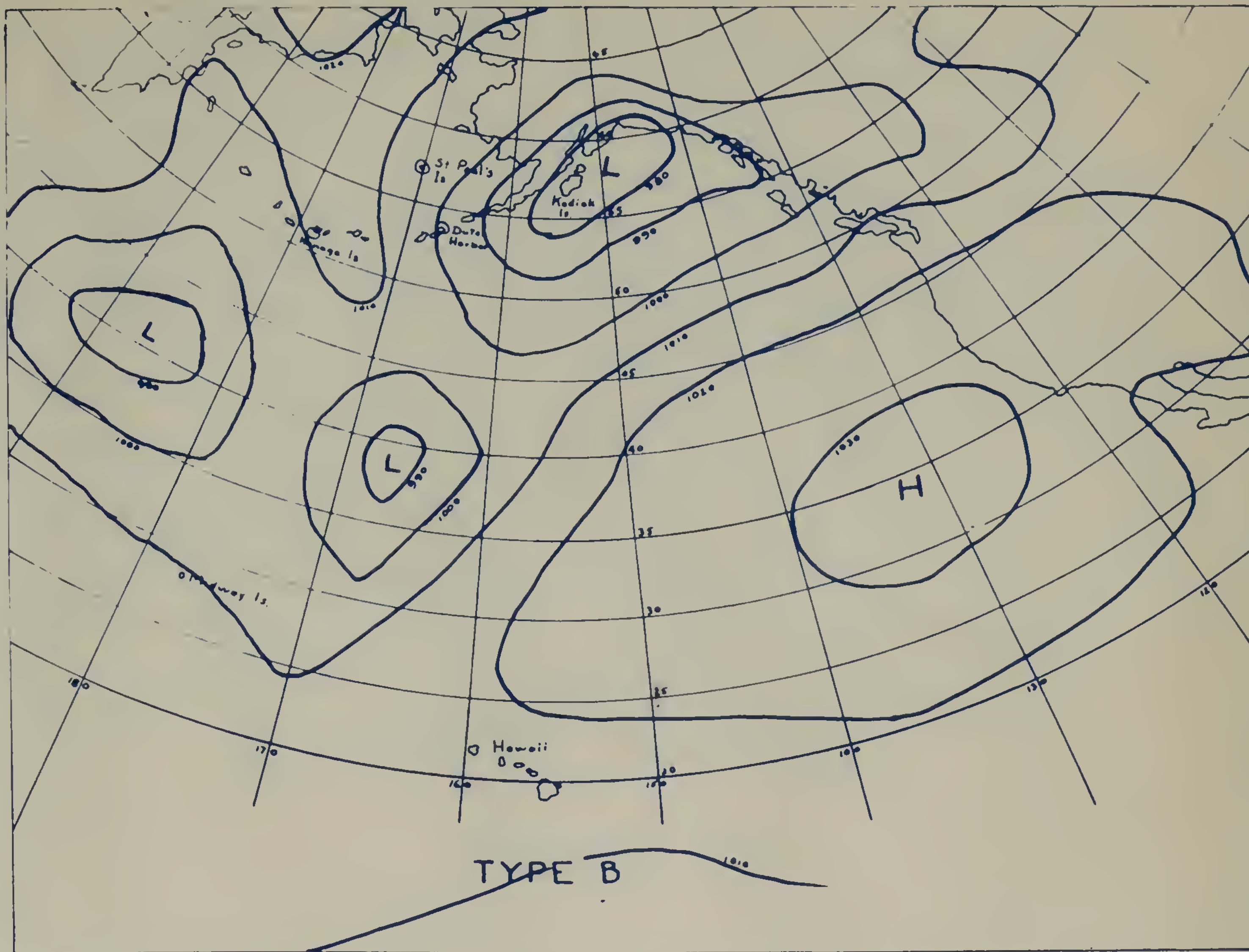
GENERAL FEATURES

The Pacific subtropical high is extensive, with the major axis lying east-west. Cyclones move rapidly along the Aleutian Islands to the Canadian Coast. Occasionally this type may have a weak and dissolving frontal system running through the middle of the area.

INDICATIONS

Type "A" will be recognized by stable conditions and high pressure at Midway, Hawaii and along the California Coast. The Aleutian and southern Alaskan Coasts and the Canadian Northwest Coast will be the scene of a chain of rapidly moving cyclones, occluding usually in the Gulf of Alaska, and disintegrating along the western mountain ranges. This type is characterized by the highest Continental-Pacific index of all types (mean value for 3 winters, 14.0 millibars).

PLATE NO. III



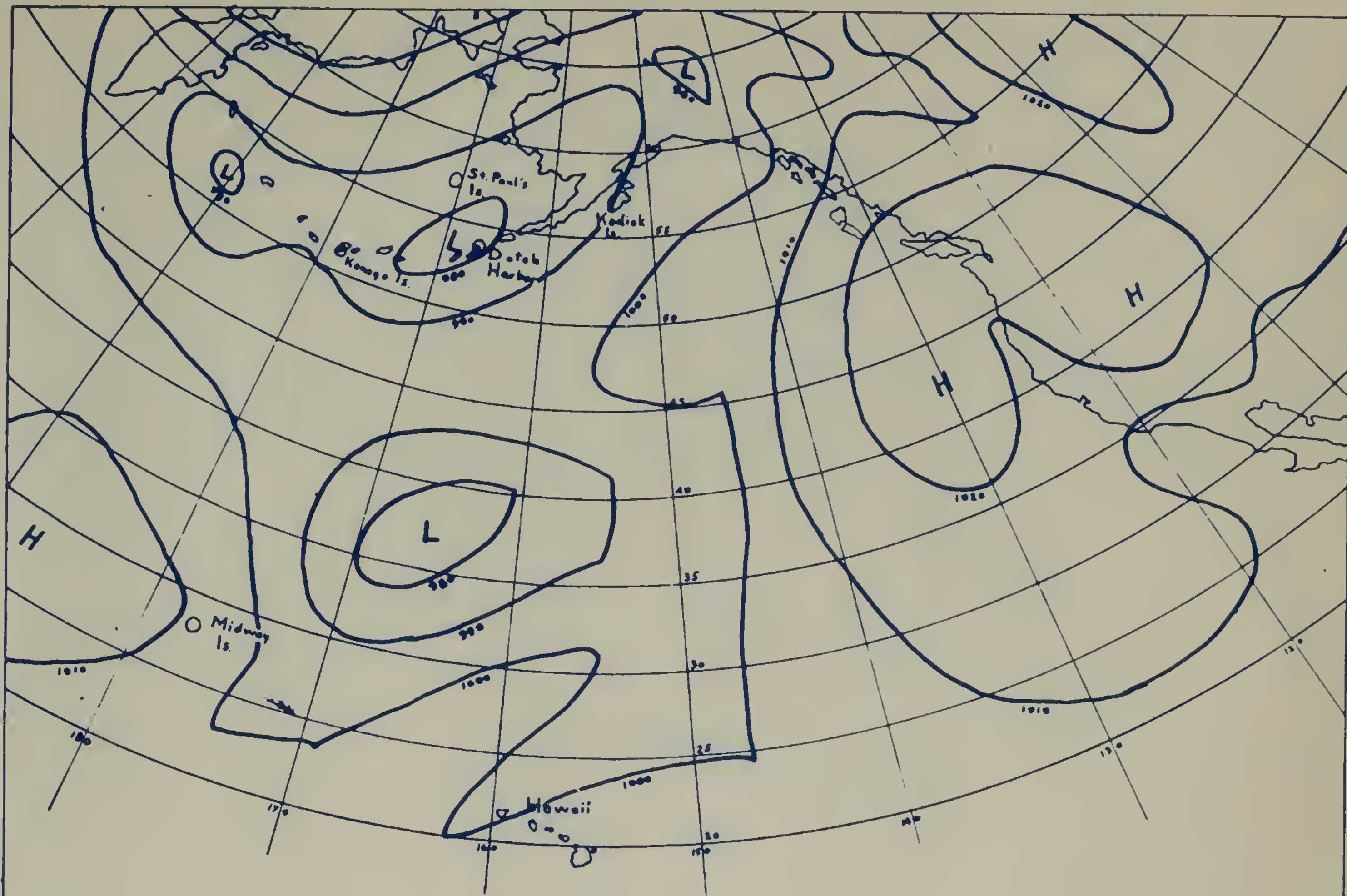
GENERAL FEATURES

The Pacific subtropical high is extensive, with the major axis lying northeast- southwest. Cyclones move from the vicinity of Midway or slightly north of that island toward the northeast to the continent, finally dying out along the mountain ranges.

INDICATIONS

Type "B" will be recognized by relatively high pressure extending to more northerly latitudes than in type "A" and steady or rising tendencies along the coast of the United States, low pressure along the Aleutian Chain extending into the Gulf of Alaska, high pressure at Hawaii, and a low pressure trough at Midway. The upper winds along the coast of British Columbia and northwestern United States will be strong steady westerlies. This type is characterized by a high Continental-Pacific index (mean value for 3 winters 13.4 millibars).

PLATE NO. IV



TYPE C

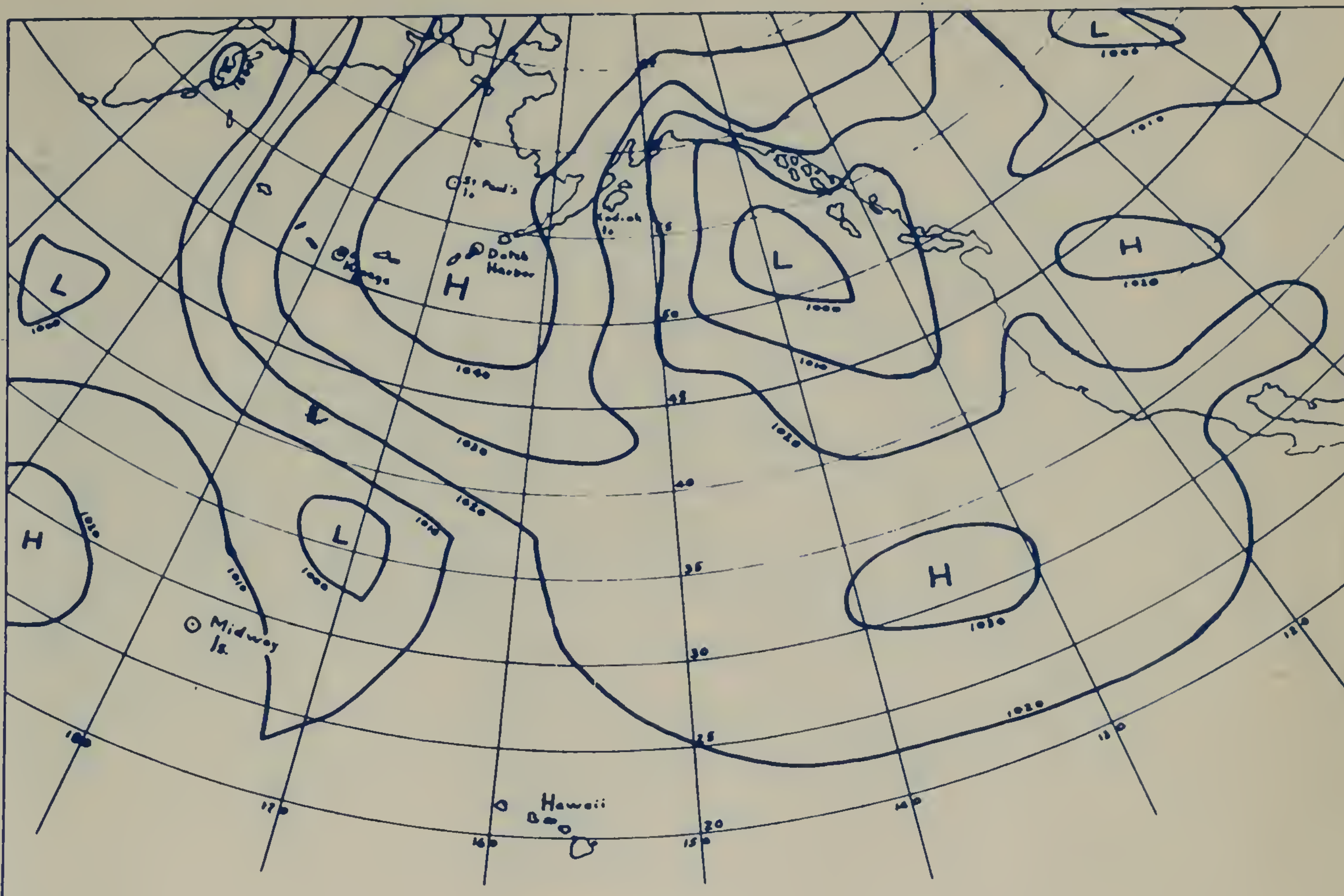
GENERAL FEATURES

The Pacific subtropical high lies in the eastern part of the Pacific along the west coast of the continent with a north-south axis. A trough of low pressure extends northward from Hawaii all the way into the Bering Sea. A large part of the Central North Pacific Ocean is, therefore, under the influence of low pressure.

INDICATIONS

Type "C" will be recognized by relatively high pressure along the coast of the United States and British Columbia, low pressure along the Aleutian Chain extending into the Gulf of Alaska, low pressure at Midway and low pressure at Hawaii. There will be a change from the prevailing easterly winds, at Hawaii, to southerly or southwesterly winds. This type is characterized by having the lowest Continental-Pacific index of all types (mean value for 3 winters 3.6 millibars).

PLATE NO. V



TYPE D_1

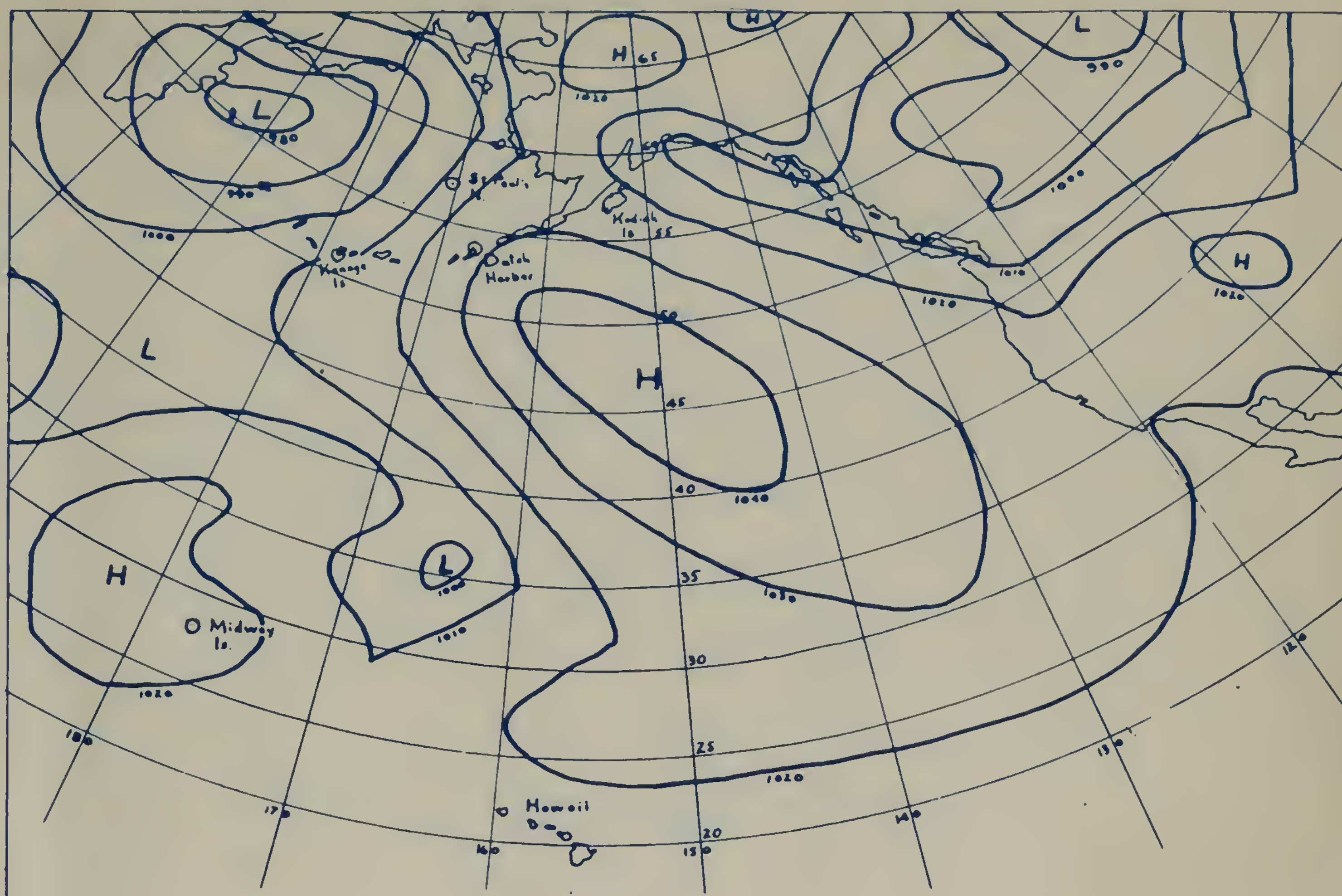
GENERAL FEATURES

The axis of the Pacific subtropical high is Northwest-southeast. There is a deepening low in the northern part of the area and the circulation is causing a reinforcement of the Pacific High by the advection of Polar Continental or Polar Pacific air.

INDICATIONS

Type "D_1" will be recognized by high pressure with steady or rising tendencies in the Aleutian Islands if reinforcement is with Polar Continental air; a deep occluded low in the northern part of the area, high pressure along the California Coast with steady or rising tendencies, and low pressure in the Midway-Hawaii area. If reinforcement is from Polar Pacific air the location of reinforcement is not discernible from mainland or island indications. This type is characterized by a moderate Continental-Pacific index (mean value for 3 winters 8.7 millibars).

PLATE NO. VI



TYPE D_2

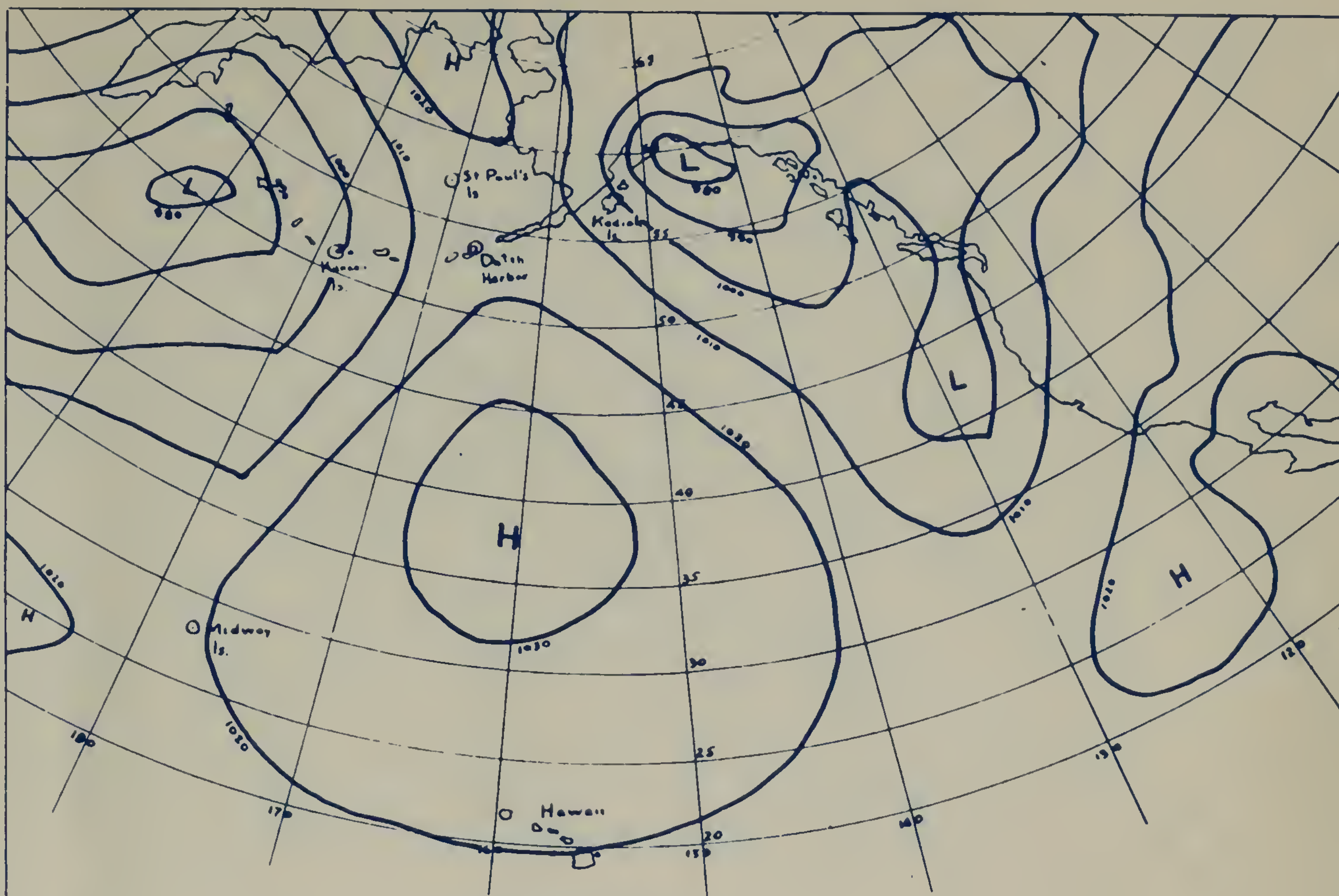
GENERAL FEATURES

This type usually follows from type "D_1" and is of short duration. The axis of the Pacific High is northwest-southeast and a chain of lows moves southeast along the North American Coast.

INDICATIONS

Northwest winds and high pressures prevail over most of the coast of North America. A high pressure exists along the eastern Aleutian Islands and the Alaskan Peninsula with, usually, falling tendencies. This type is characterized by a moderate Continental-Pacific index (mean value for 3 winters 8.4 millibars).

PLATE NO. VII



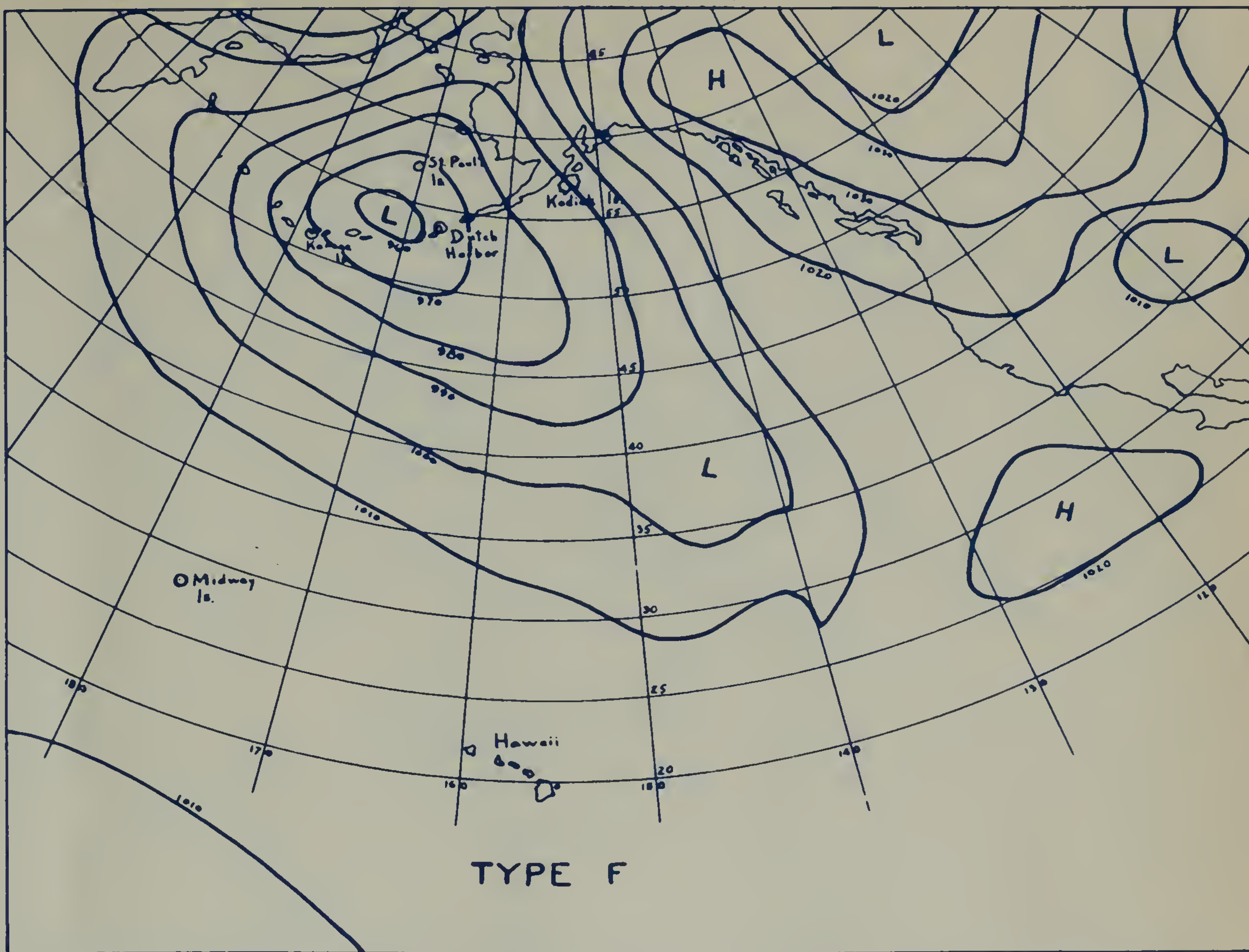
TYPE E

GENERAL FEATURES

The Pacific subtropical high lies in the west-central part of the area with a north-south axis. The west coast of North America and the eastern part of the ocean area is one of low pressure. The Aleutian Low instead of being a single center or belt of low pressure, has divided into two distinct centers with a ridge of relatively high pressure across the central Aleutian Islands.

INDICATIONS

Type "E" will be recognized by the succession of a series of cyclones moving down the coast or by the simultaneous movement of cyclones into the coastal region from both the Aleutian and sub-tropical regions. There is a high pressure at both Midway and Hawii with the prevailing trade winds at Hawii. This type is characterized by a moderate Continental-Pacific index (mean value for 3 winters 6.0 millibars).



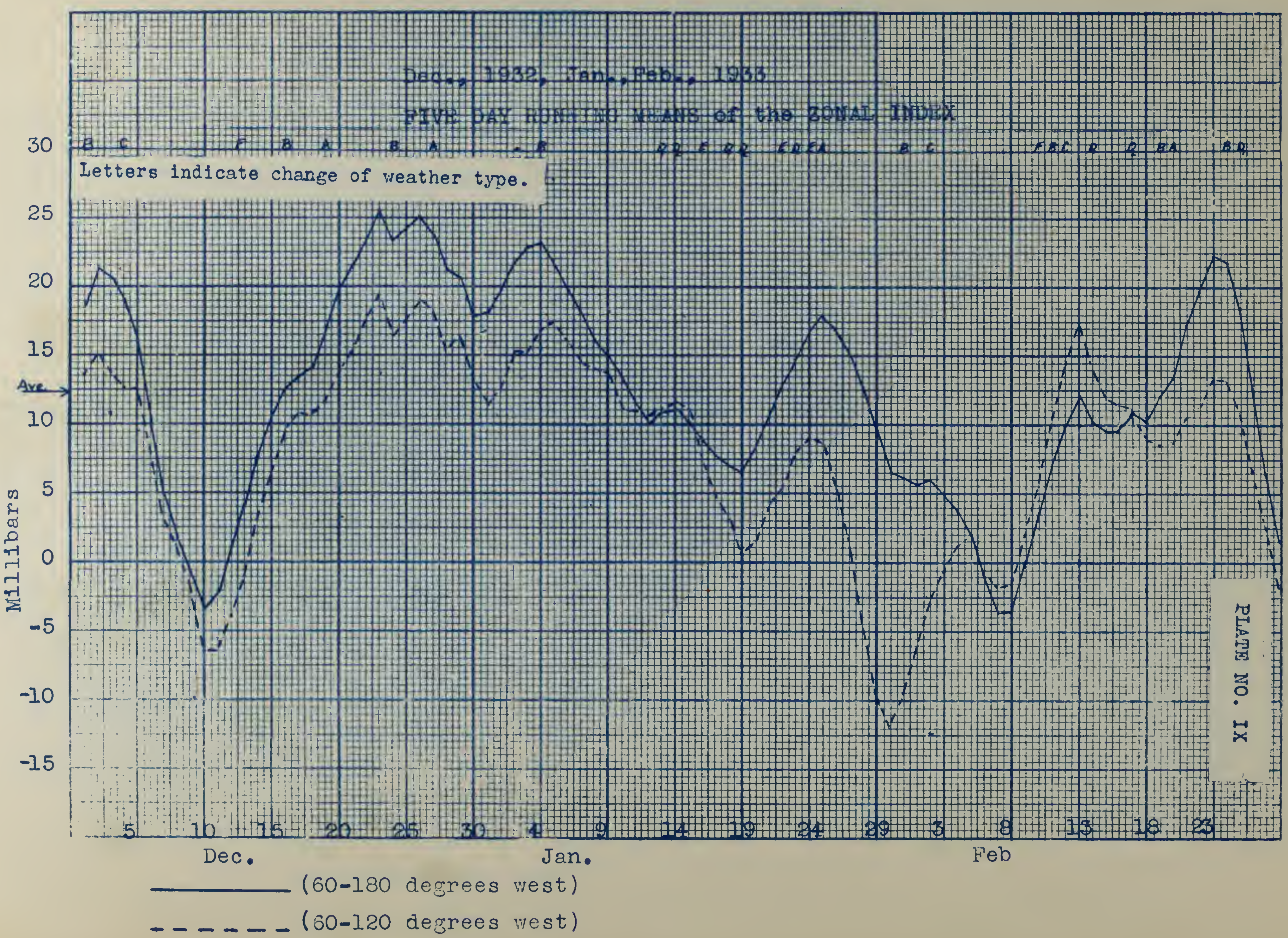
TYPE F

GENERAL FEATURES

Practically no Pacific subtropical high exists, or else the high has been displaced far to the South leaving nearly all of the area under cyclonic circulation. The Aleutian Low is near its maximum development.

INDICATIONS

Southerly winds prevail along the California Coast and westerly winds in the Midway-Hawii area. Both of these areas are subject to generally bad conditions involving frontal influences. The low center lies either over the Aleutian Area or well to the south. This type is characterized by a moderate Continental-Pacific index (mean value for 3 winters 6.5 millibars).



Dec., 1932, Jan., Feb., 1933
FIVE DAY RUNNING MEANS of the ZONAL INDEX
Letters indicate change of weather type.
PLATE NO. IX
Millibars
30
25
20
15
Ave.
10
5
0
-5
-10
-15
5
10
15
20
25
30
4
9
14
19
24
29
3
8
13
18
23
Dec.
Jan.
Feb
(60-180 degrees west)
(60-120 degrees west)

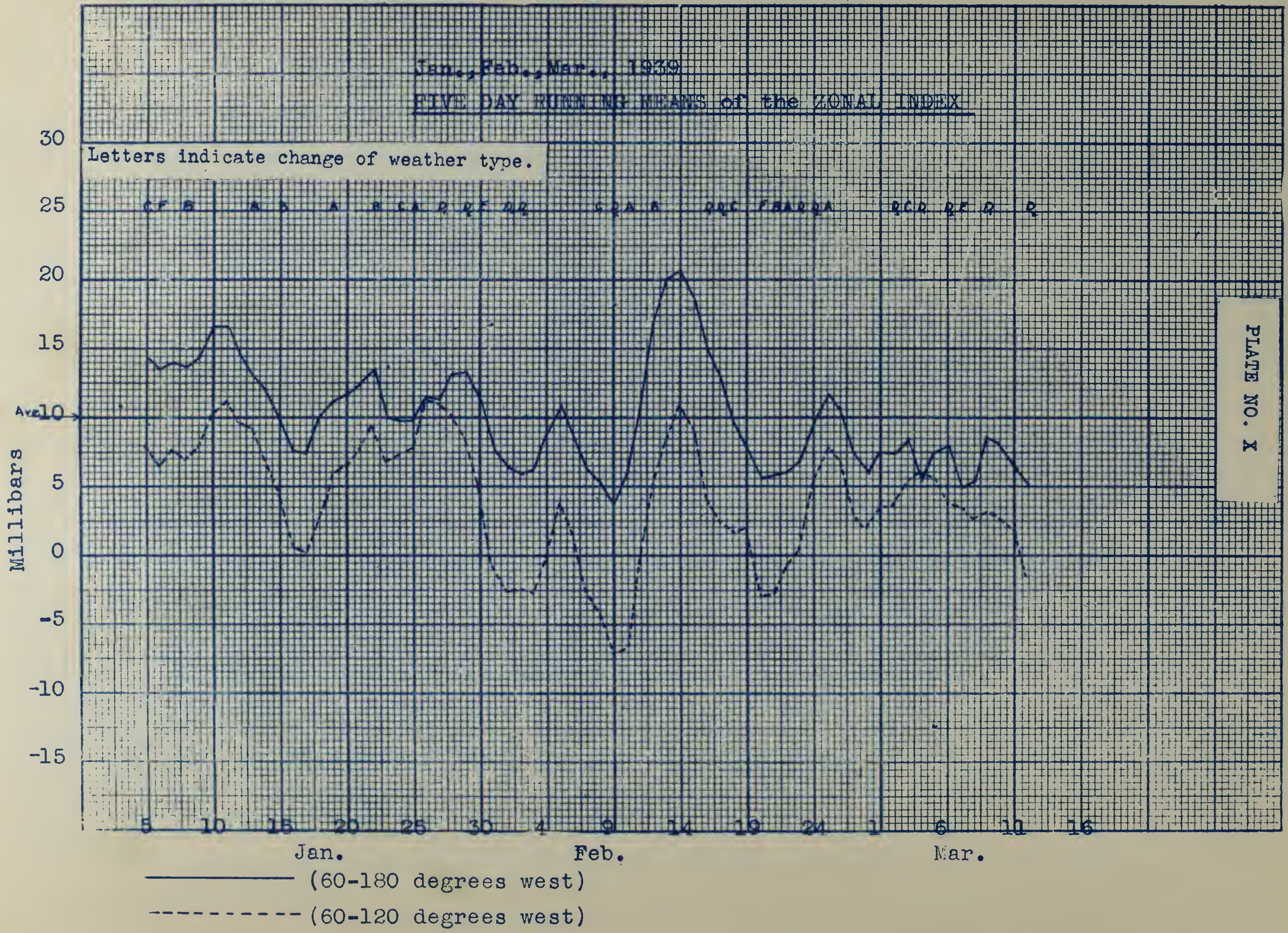


PLATE NO. X
Jan., Feb., Mar., 1939
FIVE DAY RUNNING MEANS of the ZONAL INDEX
Letters indicate change of weather type.
30
25
20
15
Av. 10
5
0
-5
-10
-15
Millibars
5
10
15
20
25
30
4
9
14
19
24
1
6
11
16
Jan.
Feb.
Mar.
(60-180 degrees west)
(60-120 degrees west)

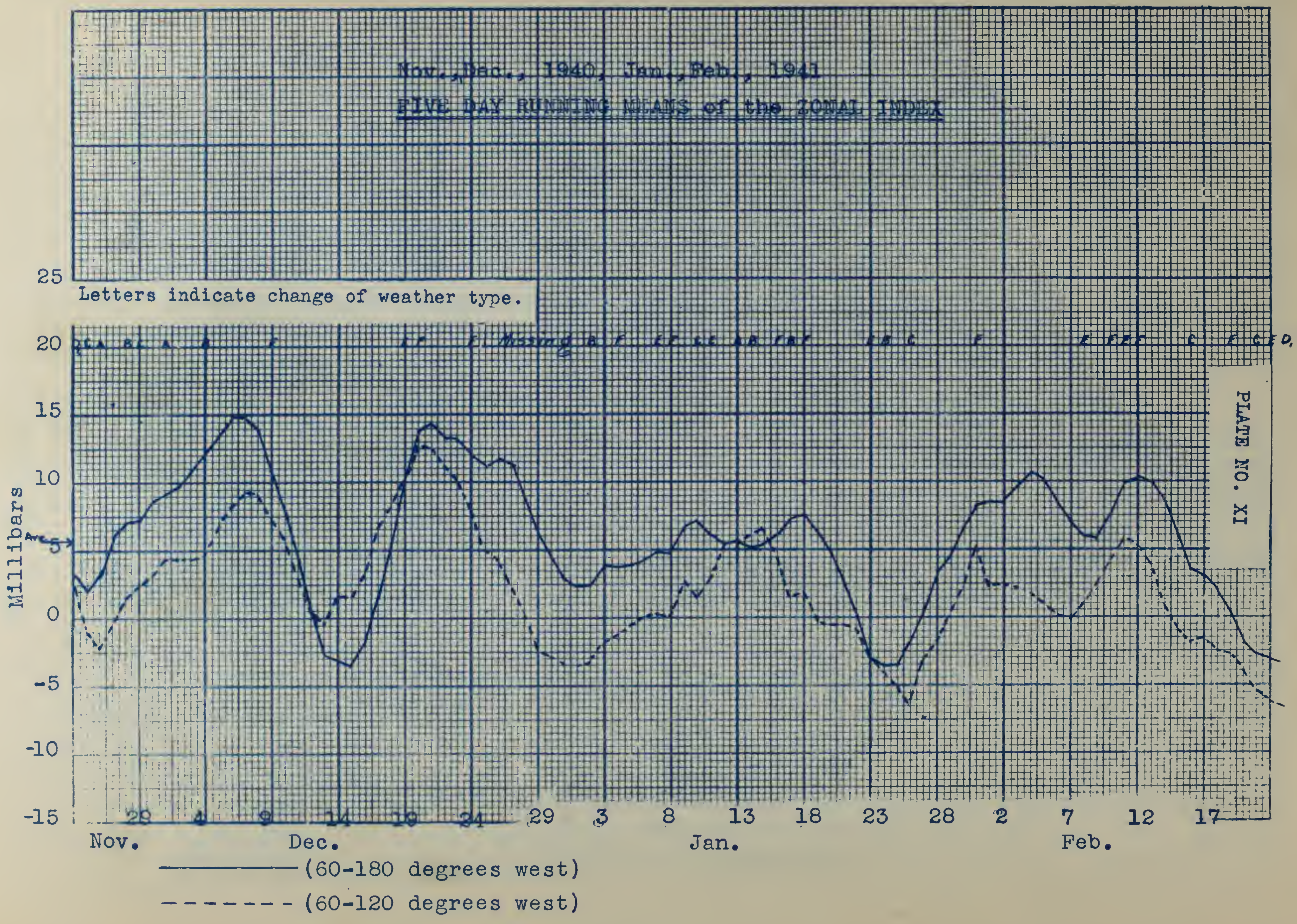


PLATE NO. XI
Nov., Dec., 1940, Jan., Feb., 1941
FIVE DAY RUNNING MEANS of the ZONAL INDEX
Letters indicate change of weather type.
Millibars
25
20
15
10
5
0
-5
-10
-15
Ave.
Missing
29
4
9
14
19
24
29
3
8
13
18
23
28
2
7
12
17
Nov.
Dec.
Jan.
Feb.
(60-180 degrees west)
(60-120 degrees west)

PLATE NO. XII

FREQUENCY OF ZONAL INDEX VALUES FOR EACH WEATHER TYPE.

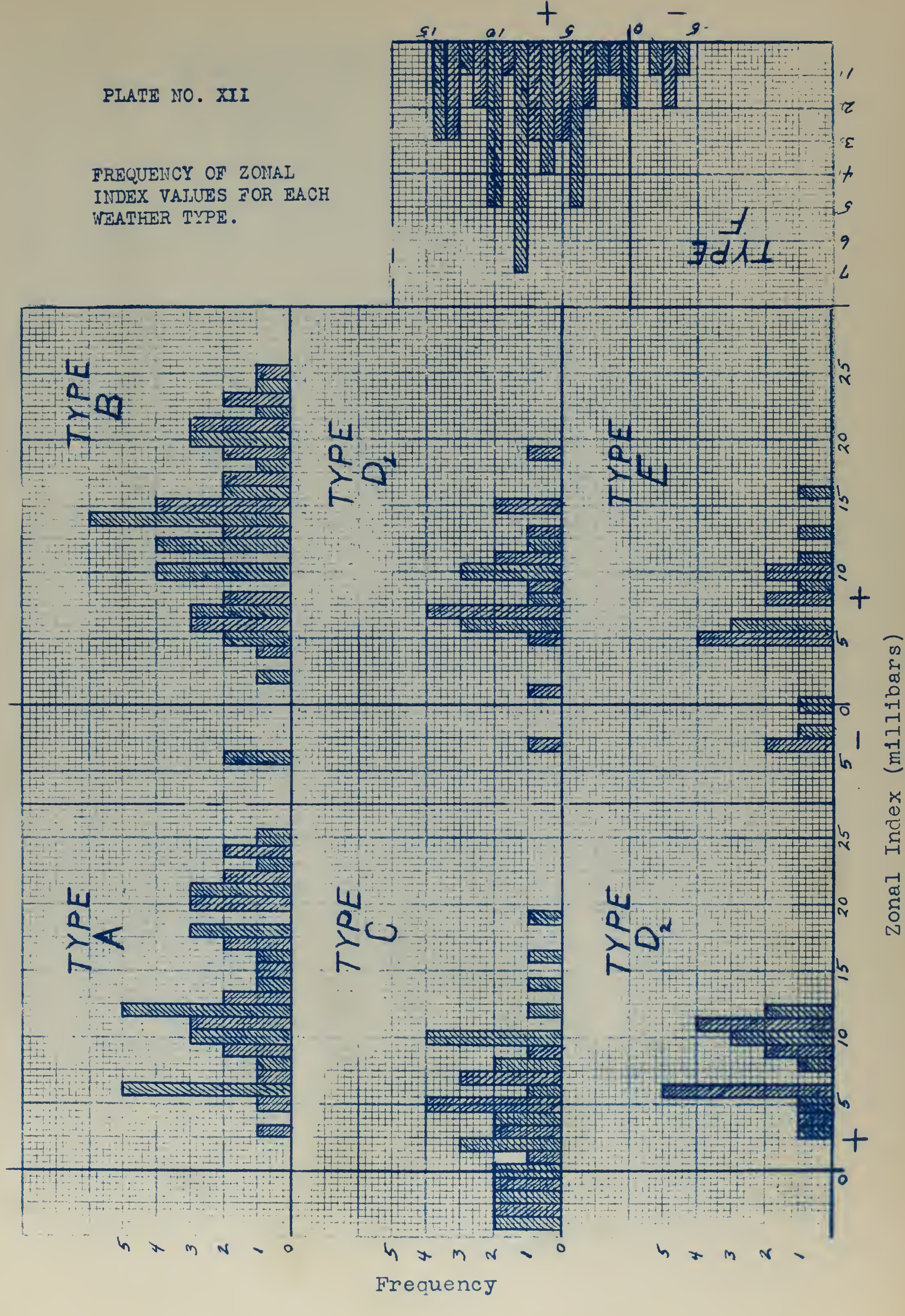
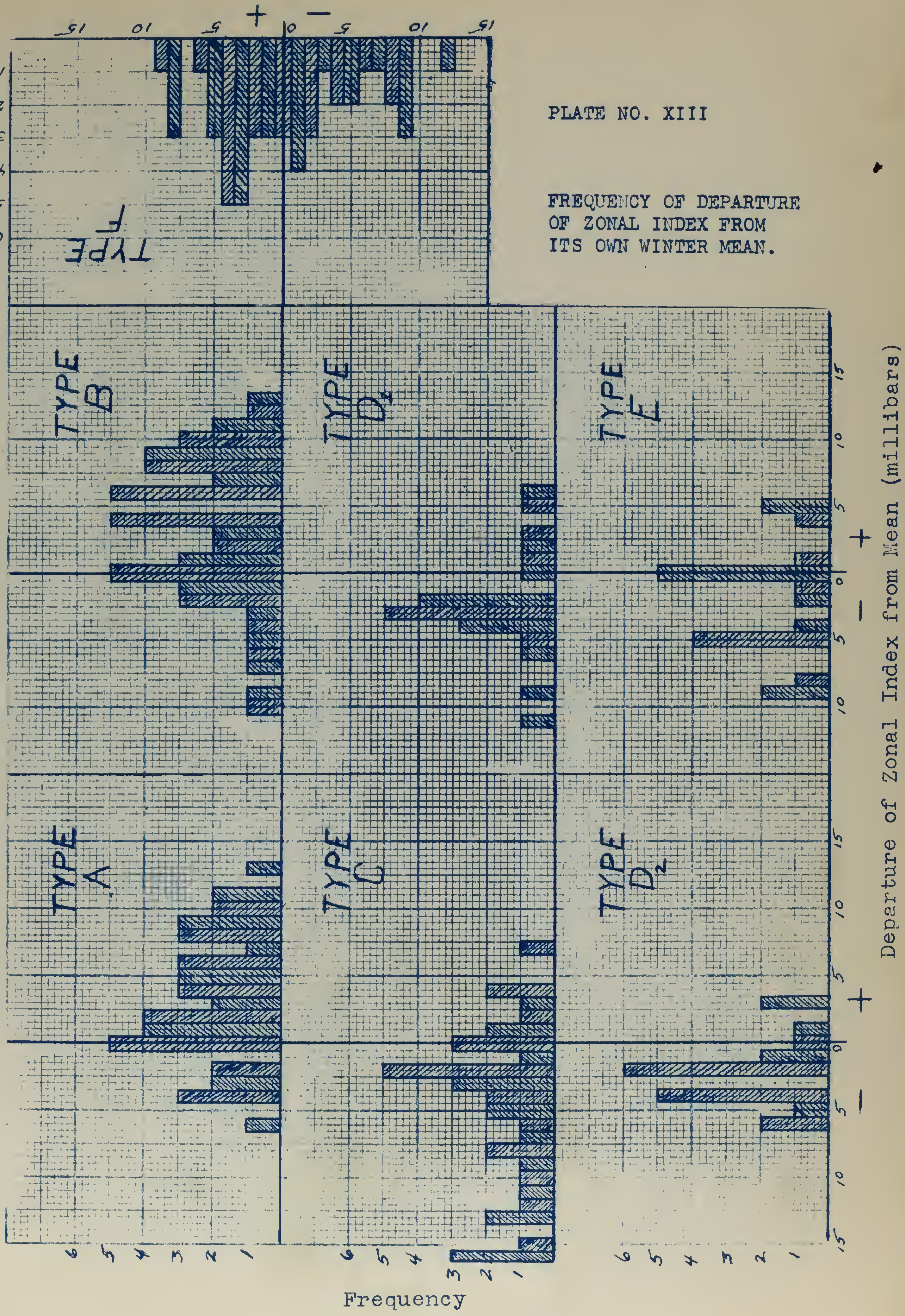
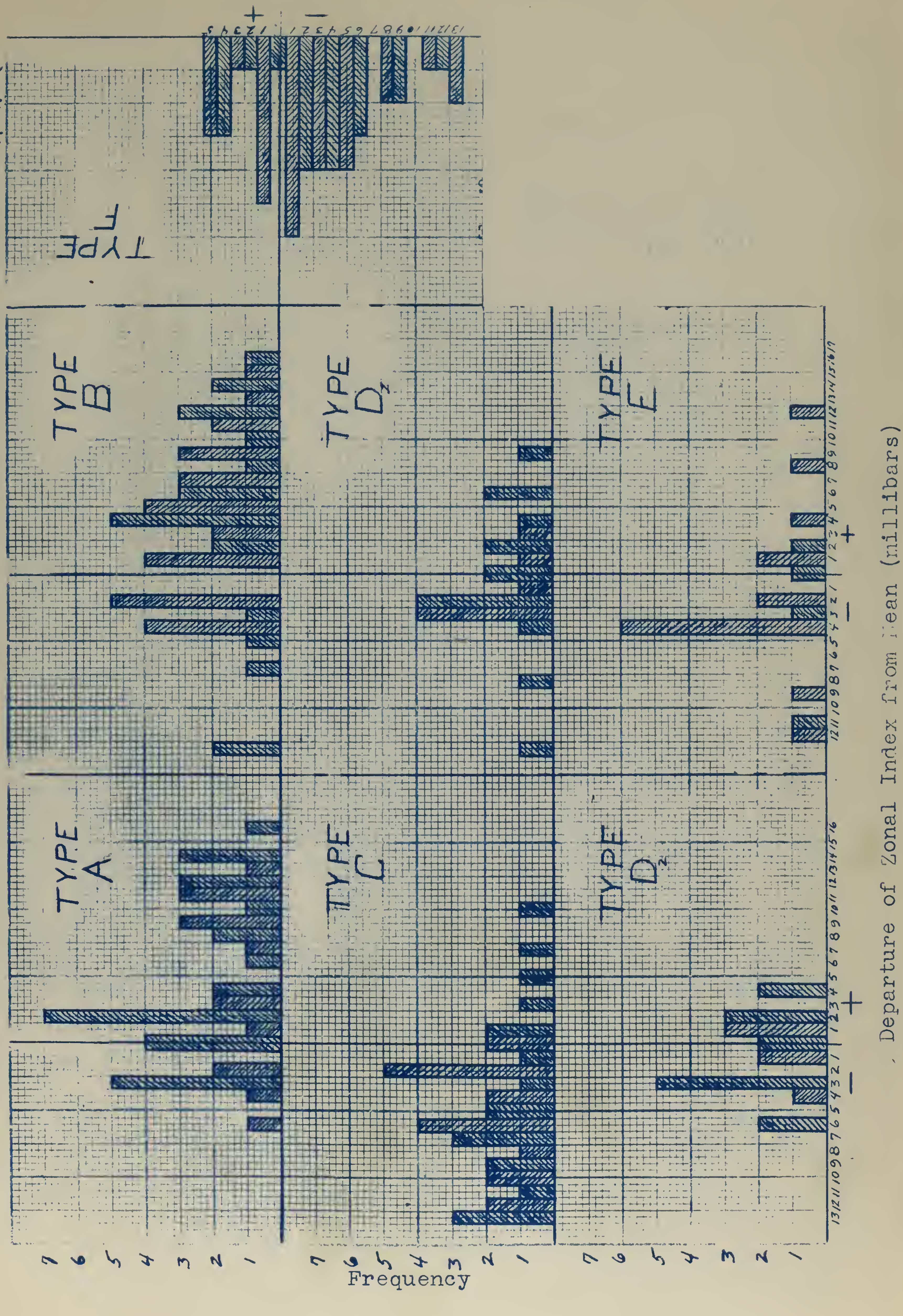


PLATE NO. XIII

FREQUENCY OF DEPARTURE
OF ZONAL INDEX FROM
ITS OWN WINTER MEAN.




TYPE A
TYPE B
TYPE C
TYPE D₁
TYPE D₂
TYPE E
TYPE F
Frequency
Departure of Zonal Index from Mean (millibars)

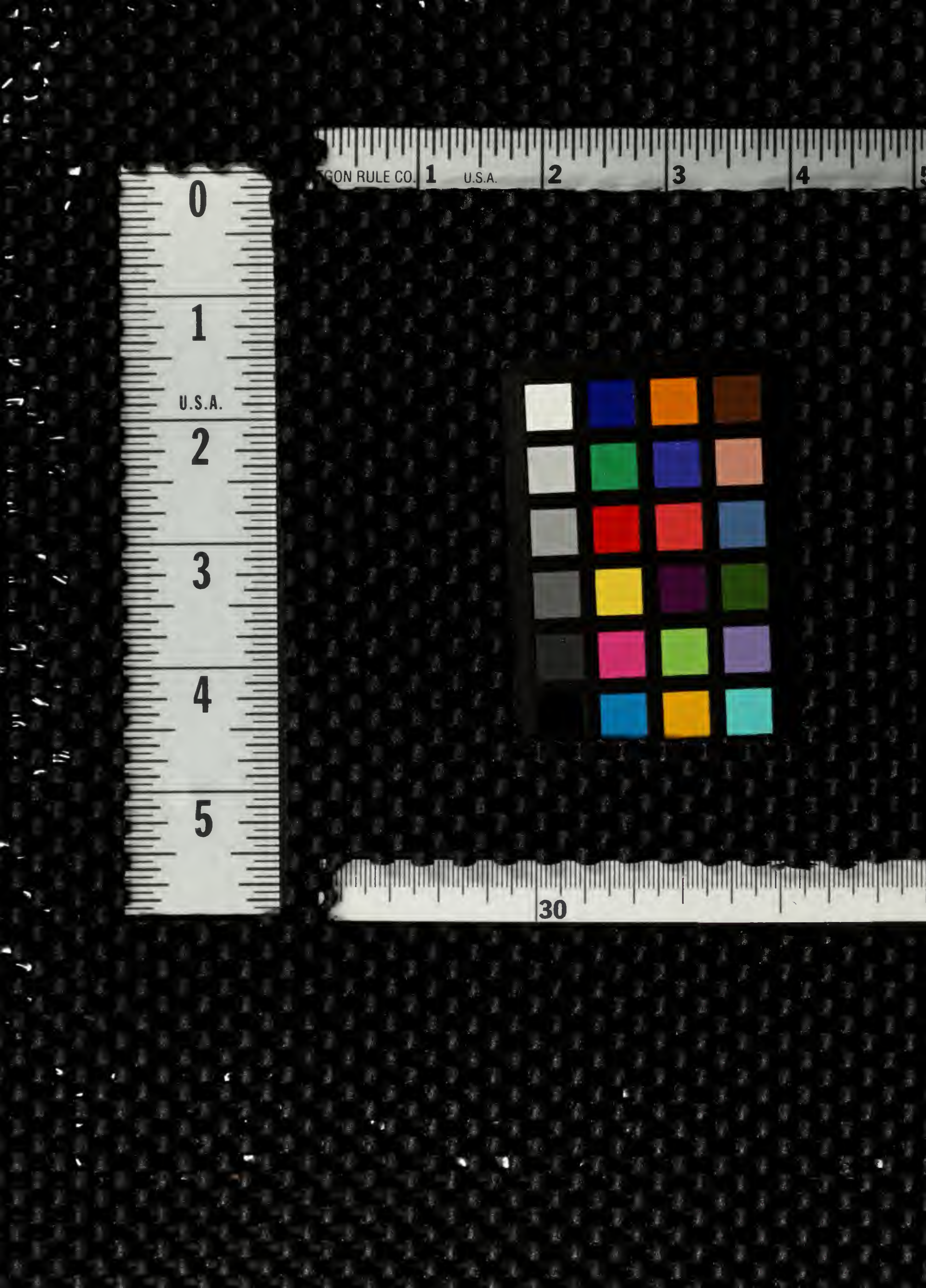
Betts

Identification of winter weather types of the eastern north pacific by means of a partial zonal index.

Thesis
B46
32852

Betts

Identification of winter weather types of the eastern north pacific by means of a partial zonal index.


GON RULE CO. 1 U.S.A. 2 3 4
0 1 U.S.A. 2 3 4 5
30